Research of Perspective Decisions Multi Mesa Impatt Diodes of the Millimeter Wave Band

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Abstract

The paper is devoted to a problem of increase of output power solid state generators mm wave band. The results of operations on development of a construction and technology extra powerful multi mesa double-drift IMPATT diodes mm wave band are reduced.

Keywords

mm Wave Band; Solid State Generator; Impatt Diode; Multi Mesa Structure Heat Resistance; Heat Sink

Introduction

At the present time to further increase the power output of solid-state generators of millimetre (mm) wave band continues to maintain its relevance, such works are carried out both in the direction of development of new wide band gap semiconductor materials (such as indium phosphide, gallium nitride) and in the direction of improving the design and technology of the most active structure [1, 2]. The QuinStar Company develops solid-state radar at W-band of continuous operation with an output power of 3-5 W [3]. Such radar in the absence of direct line of sight because of rising clouds of dust can provide a safe takeoff and landing powerful transport helicopter. Specialists of the Raytheon Company patented solid-state device non-lethal effects of mm wave that can be integrated into the design of conventional small arms [4]. Such a device according to [5] requires the development of more powerful generators mm wave.

To date the maximum power levels generated by the semiconductor devices in the mm wave band is achieved through the use of IMPATT (IMPact ionization Avalanche Transit-Time) diodes, as well as modern HEMT (High electron mobility transistor) and PHEMT (pseudomorphic HEMT) transistors.

In a continuous mode the reached levels of capacity on frequencies to 100 GHz approximately are identical to both types of devices [6].

It should be noted that this situation may change subject to the continuing development of the active IMPATT diodes based on the same material from which made modern HEMT and PHEMT transistors. This refers to the development of IMPATT diodes based on InP, and in the future, based on GaN and SiC [7, 8].

Modern production technology IMPATT diodes based on one mesa devices manufactured by using a diamond heat sink. The output level of these devices is limited to the value of thermal resistance and the temperature of overheating of the active structure. IMPATT diodes have a relatively low efficiency, not exceeding in the top 10% of the samples. Therefore the main input electrical power is converted into heat energy, causing overheating of the active structure. These limitations can be largely overcome, provided the source of heat dispersal. One of the most effective options is the use of such solutions on the surface of a diamond heat sink multi mesa design of the active device structure [9, 10]. The total area of the semiconductor structure remains unchanged (the same as in one mesa version) and is determined by the terms of impedance matching of the diode and the load. In such a structure in $\sqrt{N}$ time where N – number of mesa structure, is an increase in the perimeter of the entire active structure.

This leads to an increase in heat transfer in the lateral direction and a decrease in the thermal spreading resistance. In connection with a reduction in the total thermal resistance in multi mesa design it is possible to increase the density of the current supply and due to this several times to increase the achievable output power of microwave.

In this paper we present the results of work on the development of design and technology very powerful multi mesa IMPATT diodes mm wave band.

Multi Mesa Impatt Diodes of a 5mm Wave Band

When you create multi mesa IMPATT diodes is an

inevitable complication of device design, and a number of problems are arisen. This is to minimize the thermal interaction mesa structures, which according to calculations made in [9, 10] is reached when the value of the distance between the individual structures exceeding the diameter of 5-10 times.

Then there is a problem of minimizing the parasitic parameters. These include the parasitic inductance due to the parallel connection of individual mesa structures, the value of series resistance losses of the residual layer of the substrate, the magnitude of the parasitic capacitance of the crystal, associated with an increase in transverse dimensions and area of the upper electrode.

In [11, 12] it presented results of the development of technology multi mesa IMPATT diodes with the possibility of mounting on copper and on the diamond heat sink. The basis of this technology is the monolithic structure [13] which allows mounting on the surface of the heat sink array mesa structures with the number of individual elements down to 100.

All array elements united by a residual layer of heavily doped substrate with on top of her total disc electrode. As a laboratory prototype in [11, 12] were obtained 6 and 8 mesa, silicon p^+p-n-n^+ double-drift IMPATT diodes 5mm band on a copper heat sink. Figs. 1, 2 contain electronic images of the samples of these devices after etching of the active semiconductor structure.

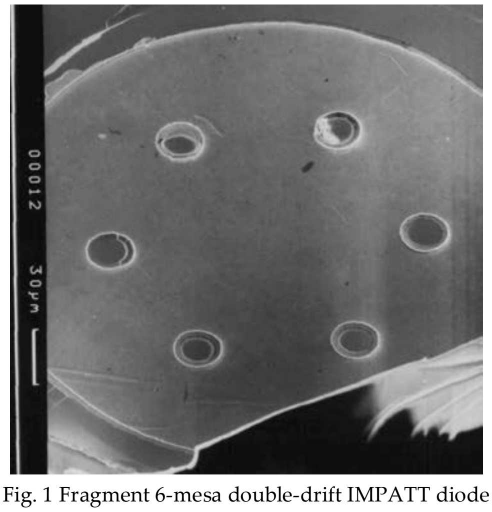

Fig. 1 Fragment 6-mesa double-drift IMPATT diode

In Fig.1 the bottom electrodes 6-mesa the device are represented located on golden surfaces of a copper heat sink on a circle in diameter near 180 micron. The distance between separate mesa structures with individual diameter about 16 microns makes 90 microns. Similarly on photo 2 the bottom electrodes 8-mesa the device with individual diameter about 14 microns is located on a circle in diameter about 120 microns. Laboratory samples of IMPATT diodes multi mesa examined for termovizor Agema Infrared Systems Thermovision 880 with a detector of mercury cadmium telluride coated with 8-12 microns, operating in photoconduction mode.

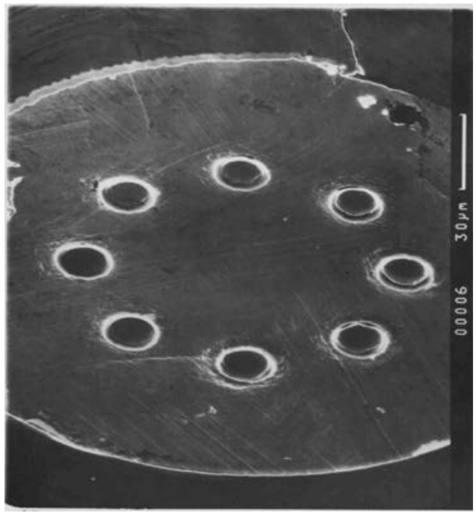

Fig. 2 Fragment 8-mesa double-drift IMPATT diode

Fig. 3 shows a sketch of the investigated structures multi mesa structures.

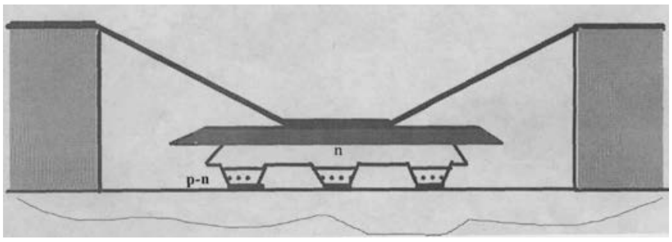

Fig. 3 Sketch of multi mesa IMPATT diode

The height of the structures did not exceed 10 microns. Given the unilateral removal of heat from the massive heat sink, you can assume that in steady state continuous thermal regime of p-n junction temperature and the surface of the upper electrode mesa structures equal to each other with great accuracy.

Fig. 4 gives a typical picture of the field temperature heat 6-mesa silicon double-drift IMPATT diode 5mm wave band after holding it for 15 minutes at an input power of 5.2 W and an ambient temperature of 28°C. Zones with the same temperature overheating and within each zone specified minimum temperature of overheating. The maximum temperature of overheating of the upper electrode was measured separately and in this case was 110°C.

The ratio of the maximum temperature of overheating of the upper electrode to the input of electrical power equal to the thermal resistance of IMPATT diode in

this mode of operation was about 21°C/Watt. This is 2-2.4 times less than the corresponding values for silicon one mesa IMPATT diode on a gilded copper heat sink with an area equal to the p-n junction (about 1.8–10^{-5} cm^{-2}) is about 45-50°C/Watt.

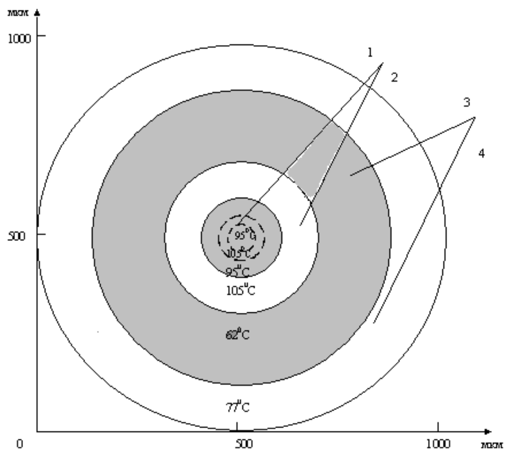

Fig. 4 The picture of the temperature field overheating 6-mesa IMPATT diode 5mm wave band, resulting in thermovisor Agema Infrared Systems Thermovision 880: 1 - zone of the upper electrode , 2 - surface of the heat sink inside the hard terminal 3 - hard terminal surface 4 - is the surface of the heat sink out of hard terminal

Reducing the thermal resistance of silicon double-drift IMPATT diode 5mm wave band to 21°C/ W by using 6-mesa design has allowed measuring the output characteristics for an input power of 10 W or more in a continuous mode.

For 6-mesa devices with a hard terminal on the basis of the ruby plug in height 0.2mm, internal diameter 0.4mm and external diameter 0.8mm had been received record values of level of continuous output microwave power.

The most typical results are presented in Table I. Here parameters of the best laboratory samples where $\Delta_2 T_{p\text{-}n} = (P_{in} – P_{out})\ R_T$ – the overheat p-n junction taking into account that the input power part doesn't dissipate in the form of heat, and is transformed to output microwave power, an overheat $\Delta_1 T_{p\text{-}n} = P_{in}\ R_T$ in case of P_{out} = 0 are resulted.

Decrease in thermal resistance for 6-mesa devices has allowed making measurements at level of input electric power to 10 W. The best result is value of level of output microwave power of 1.04 W on frequency of 65.9 GHz at efficiency of 10% and temperature of an overheat of active structure less than 200°C.

The received results have been substantially caused by that all mesa structures have been united by residual layer N^+ of substrate of the thickness 10-12 microns with the general top disk electrode located on it in diameter about 250 microns.

It has allowed to minimize size of parasitic inductance a multi mesa crystal and to provide in phase work of all structures.

TABLE I PARAMETERS OF LABORATORY SAMPLES 6-MESA DOUBLE-DRIFT IMPATT DIODES WITH BREAKDOWN VOLTAGE U = 23,7 V

C(0) pF	R_T, °C/W	I mA	P_{out}, mW	F_{gen}, GHz	$\Delta_1 T_{p\text{-}n}$, °C	$\Delta_2 T_{p\text{-}n}$, °C	η %
1,4	21	200	450	65,8	124	114	7,7
		240	500	65,8	152	142	6,8
		270	750	62,2	176	159	7,5
		290	850	65,3	191	174	8,5
		300	920	65,3	200	180	9,2
		325	1040	65,9	218	196	10
1,2	22	175	340	66,8	112	104	6,7
		225	640	67	150	136	9,4
		250	720	67,5	170	155	9,3
		275	820	68	190	173	9,4
		300	980	68,3	212	190	9,8
1,4	22	250	650	66,5	153	138	8,6
		300	840	67	208	190	8,9
		330	1000	67,5	232	210	9,5

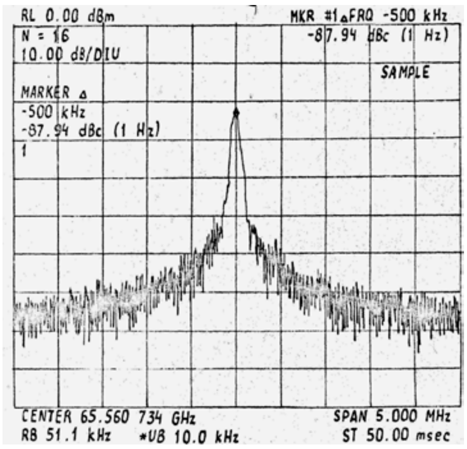

Fig. 5 Form of output microwave signal generated with 6-mesa IMPATT diode

Fig. 5 shows the shape generated by a 6-mesa IMPATT diode output microwave signal, indicating in-phase operation of all six mesa structures.

However the considerable size of length of a passive layer of a substrate and the parasitic capacity caused by an insufficient backlash between the bottom basis

and N^+ layer, in this case equal to height of an individual mesa structure (about 4 microns), haven't allowed to reach expected value of efficiency about 15%. It is necessary to notice that the technology resulted here could be tested with use of a diamond heat sink. It practically guaranteed even more than 2 multiple decreases in thermal resistance and proportional increase in level of output microwave power.

3-mesa Double-drift Impatt Diodes of 3 mm Wave Band

In [14, 15] it is successfully realized 3-mesa GaAS double-drift IMPATT diode 3mm wave band in which design almost completely it was possible to eliminate parasitic parameters listed above multi mesa device. Three mesa structures in diameter on 20 microns are established on the general heat-removing diamond basis. They are carried on a circle in diameter in 100 microns and supplied by the general top disk gold electrode. Thus the mesa structure height is minimized to 2-3 microns, and distance between the bottom basis and the general top electrode, at the expense of use of additional gold columns on a surface of mesa structures makes about 10 microns.

Such diode assemblage doesn't need the classical hard terminal consisting of a tape conclusion and the dielectric plug. A food is brought directly to the top electrode through a resonant cover in diameter 200 microns. The given approach has allowed reaching on frequency of 91GHz record level in a continuous mode of output microwave power nearby 500mW at efficiency of 9% that exceeds in 2.5 times level of power and efficiency at use of the same semiconductor structure in usual one mesa designs. Nevertheless, the described way possesses an essential lack: the quantity of mesa structures in multi mesa designs which can be received on the given way is limited to technical possibilities of a photolithography which is carried out from the residual layer of a substrate which do not possess the demanded class of a surface.

Design a Multi Mesa Crystal with a Concave Top Electrode

In [11] it experimentally tested design of IMPATT diode with a special, the concave shape of the upper electrode. It has allowed to minimize height of a mesa structure to 2-3 microns, having left thus hanging edges of the top electrode at height not less than 10-12 microns. On the Fig. 6 (a, b) photos of the diode with the concave form of the top electrode are presented.

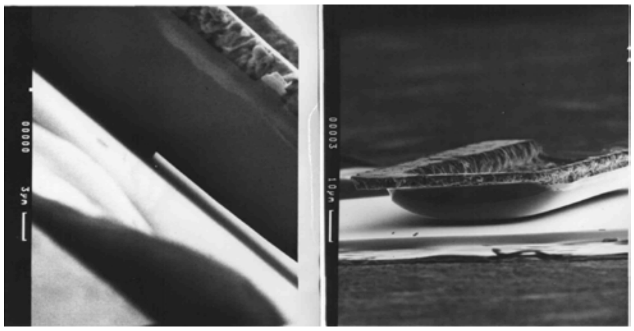

Fig.6 Photo of the double-drift IMPATT diodes with the concave form of the top electrode: a – side view, b – the top view

Considerable reduction of consecutive resistance of losses and parasitic capacity of a crystal has allowed even in one mesa a variant to receive for identical [11, 12] double-drift structures level of output microwave power 540mW on frequency of 62.5 GHz, at the raised efficiency of 12.8% and temperature of an overheat of active structure nearby 200°C. Such approach is an important element of improvement offered in given work multi mesa designs [11].

Namely on a way [13, 16] will be formation of working contacts and etching of mesa structures from the working party of a plate (is made from active junctions) that will allow to use to the full resolving possibilities of a photolithography and "dry" methods of etching. Before formation of an integrated top electrode, it is provided combined with the bottom working contacts additional local etching from a substrate with its subsequent metallization. Further it is formed, combined with the general top disk electrode, the technological mesa structure connected to working mesa structures by the general residual layer of substrate. The technological mesa structure allows manipulating a micro miniature file of mesa structures of any form at its installation on a heat sink. After installation on a heat-conducting path the technological structure leaves on a mask of the top electrode which in the subsequent can carry out function or a resonant cover or a basis for formation of more hard terminal on the basis of dielectric plugs.

Conclusions

In given article the most productive works on multi mesa IMPATT diodes of mm wave band are investigated. The maintenance of these works speaks about existence of a considerable is constructive-technological reserve in the field. Use and development of the given reserve will allow to reach much higher levels of output microwave power in mm

a range, for carried out of traditional materials (silicon, gallium arsenide), multi mesa IMPATT diodes.

In particular possibility of escalating of quantity of elements in multi mesa active structure which means can be mounted on a diamond heat sink. Such devices could provide not only much higher levels of output microwave power of generation, but also simultaneously lower working temperatures of an overheat of active structure and accordingly the big reliability and durability of devices on their basis. It is necessary to note also use possibility multi mesa designs for decrease in pulse thermal resistance in pulse operating mode of IMPATT diodes. Corresponding calculations are resulted in work [17]. Fulfilled on traditional materials (silicon, gallium arsenide) the multi mesa technology can become a basis for the fullest use of the electronic microwave power of resource IMPATT diodes on the basis of more perspective materials such as indium phosphide, gallium nitride and silicon carbide. Authors of work offer scientifically technical cooperation to all persons interested in given researches and the organizations.

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